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Global characteristics of $^{197}\mathrm{Au} + ^{197}\mathrm{Au}$ collisions at 23 AMeV

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Abstract

We present the current status of nuclear dynamics studies performed by the BREAKUP group with the 4π CHIMERA array, for the system $^{197}Au + ^{197}Au$ at 23 AMeV.

Nuclear dynamics studies have been performed by the BREAKUP group for the system $^{197}Au + ^{197}Au$ at 23 AMeV with two goals: (i) a search for toroidal freeze out configurations predicted to be formed for this heavy system [1]; (ii) an extension of an earlier study carried out at a lower energy of 15 AMeV, in which a new reaction mechanism of violent collinear breakup of non-fusing colliding systems into 3 and/or four massive fragments was discovered [2].

The search for exotic nuclear configurations was inspired by J.A.Wheeler [3]. His idea was investigated by many authors who studied the stability of exotic nuclear shapes (see e.g. [4]). Theoretical investigations related with the synthesis of long-living nuclei beyond the island of stability have shown that they can be reached only if non-compact shapes are taken into account. Calculations for bubble structures showed that such nuclei can be stable for $Z > 240$ and $N > 500$ (see e.g. [5]). Recently it was found that for nuclei with $Z > 140$ the global energy minimum corresponds to toroidal shapes [6]. In contrast to bubble nuclei, the synthesis of toroidal nuclei is experimentally available in collisions between stable isotopes.

To address this issue simulations for Au + Au collisions in a wide range of incident energies using the BUU code were performed [7]. These calculations indicate that the threshold energy for the formation of toroidal nuclear shapes is located around 23 MeV/nucleon. Also Improved Quantum Molecular Dynamics Model calculations performed for U + U collisions have shown the possibility that toroidal freeze-out configurations can be created above a specific collision energy for this heavy system [8]. Such toroidal-shape complex can be also created in macroscale in binary droplet collisions above some threshold velocity [9].

The simulations of decay process of different break up configurations using the ETNA code were performed to study the applicability of the CHIMERA detector [10] for recognition of non-compact nuclear objects. Detailed analysis of different observables have shown that the efficiency factor of events with 5 heavy fragments can be used as a signature of formation of toroidal configurations [11].

The experiment for the Au + Au reaction was performed in March 2010 using the CHIMERA detector. The total number of collected events is of the order of 10^8.

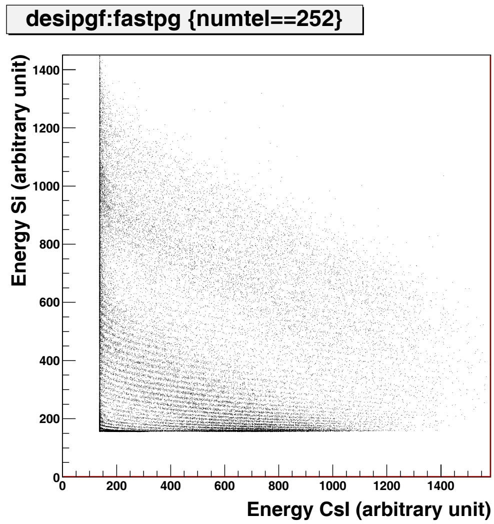

Figure 1: $\Delta E - E$ for fragments detected in telescope placed at $\theta = 10.8^o$.

During the experiment two gold targets were used: 164 and 396 $\mu g/cm^2$. The thinner target was used in calibration measurements and the thicker one in the production runs.

The collected data are calibrated using a set of dedicated programs developed at LNS-INFN. Our calibration procedure include: (i) energy calibration of Si detectors, (ii) charge identification of fragments, and (iii) mass identification of fragments. Energy calibration of Si detectors was performed using ion beams, delivered both by the tandem and the cyclotron. Data for the following systems were used: (i) the elastic scattering data for $^{16}O + Au$ at 60 and 80 MeV, $^{58}Ni + Au$ at 142 MeV, Au + Au at 170 MeV and 23 AMeV; (ii) recoil peak for $Au +^{12} C$ at 170 MeV; and (ii) fission fragments from $Au +^{12} C$ reaction at 23 AMeV.

In order to identify fragments punching through the silicon detector we employ the $\Delta E - E$ technique. In Fig. 1 an example of $\Delta E - E$ plot is shown for a detector belonging to the 5-th internal ring, at a polar angle $\theta = 10.8^o$. The Z spectra of fragments observed by telescopes located on rings at three different angles are presented in Fig. 2. We can see that in the Z spectrum corresponding to the telescopes located at $\theta = 12.25^o$ good charge identification can be observed up to Z=35. For higher charges due to limited statistic it is difficult to select lines corresponding to individual Z value for a given detector. Going to larger observation angles the charge distributions are much stepper.

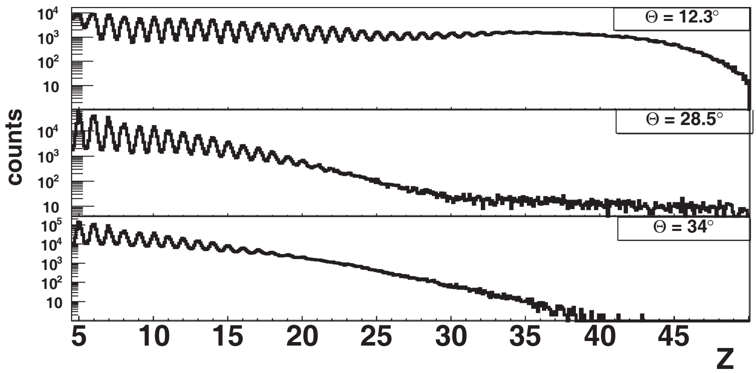

Figure 2: Z spectra for fragments observed in telescopes located at $\theta = 12.25$, 28.5 and 34^o

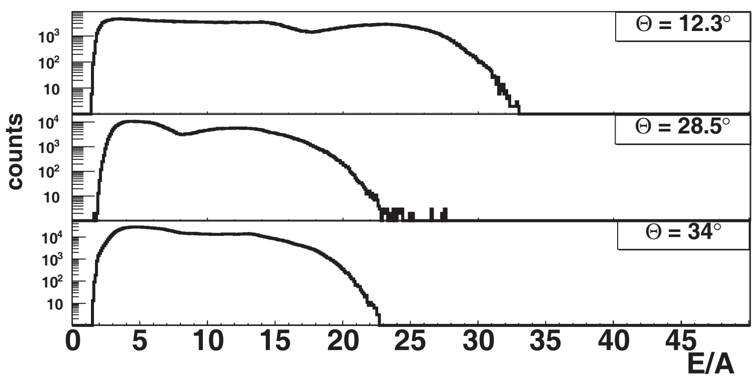

Figure 3: The kinetic energy per nucleon spectra for the same class of particles as presented in Fig. 2

Fig. 3 presents energy spectra of fragment with charge from 5 to 50 observed at the same angles as in Fig. 2. Here the energy of each fragment is normalized to its mass. At the smallest angle of observation the energy corresponding to higher maximum corresponds to the beam energy.

For the identified fragments we have constructed the plot presenting the dependence between the total charge of identified fragments versus total parallel momentum of those fragments (Fig. 4). As we can see our events are incomplete. In the case of the most complete events the total detected charge is of the order of 50% of the system charge. Substantial fraction of particles was not identified using $\Delta E - E$ method. In this group of unidentified particles we have fragments which are stopped in silicon detector

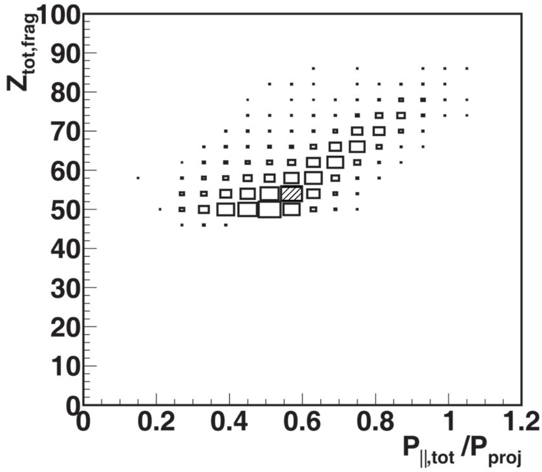

Figure 4: The correlation between the total charge of identified fragments versus total parallel momentum of those fragments

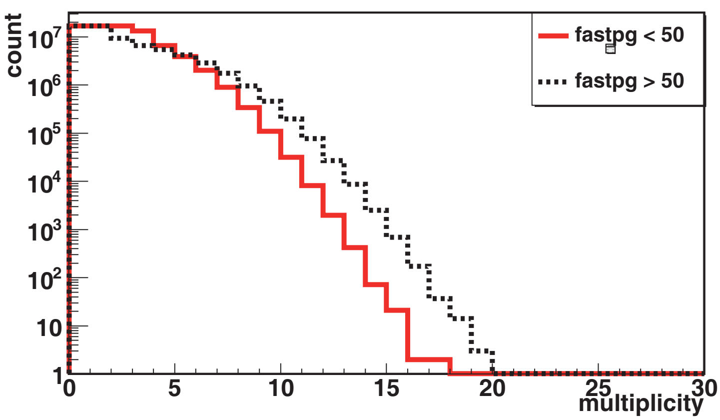

Figure 5: (color online) Multiplicy distributions of unidentified particles detected in Si detectors. The particles stopped in Si - red curve, particles punching through - black curve.

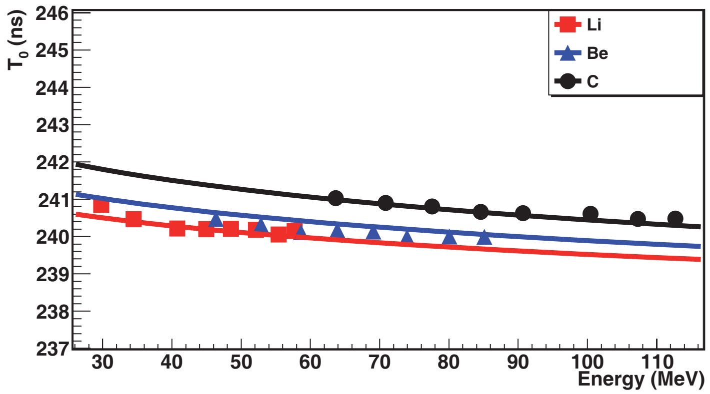

Figure 6: (color online) The t_0 parameter vs kinetic energy of identified Li, Be, and B ions for detector located at $\theta = 74^o$

and light particles like protons and $\alpha's$. Some raw information about the contribution of heavy fragments stopped in Si detectors can be extracted from Fig. 5 where multiplicity of recorded particles is presented. Here the red curve corresponds to particles stopped in silicon detector (mostly heavy fragments) and the black curve correspond to fragments (already identified) and light particles passing throught. As one can see the multiplicity of both categories of particles is similar and substantial part of the total system mass and charge can be related with heavy fragments stopped in Si detectors.

For the class of particles stopped in Si detectors the identification procedure is in progress using the Time of Flight Method. The t_0 parameter dependence on incident enegy and particle mass is under investigation.In Fig. 6 the observed dependence of t_0 on kinetic energy and mass of Li, Be and B ions is shown for the detector located at $\theta = 74^o$. Here points coresponding to the position of well identified Li, Be, and B ions are compared with phenomenological fit.

Completion of the mass identification of fragments stopped in Si detectors for all CHIMERA telescopes will enable us to get more complete information about the measured events. It will be possible to proceed with search for toroidal freeze out configurations and investigation of violent collinear breakup process.

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